Physics 222, Homework Set #26

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Chapter 15, Q14:

First, we consider the reverse process: the hot air (+60°C) and the cold air (-20°C) are combined together to get 20°C air. This reverse process can occur, since the total entropy increases in this irreversible process. So, it seems that the original process can't occur, since the total entropy will decrease. The second law of thermodynamics tells us that the in an irreversible process, the total entropy of an ISOLATED system always increases. Is this system isolated? In order to keep one flared end at +60°C, there is a heater or filament inside the tube. The heater adds heat to this system. Thus, this system is NOT an isolated system. So the original process can occur, and does not violate the second law of thermodynamics.

Chapter 15, P3:

The thermal efficiency e of a heat engine is defined as: $e \equiv \frac{W}{Q_h} = 1 - \frac{Q_c}{Q_h}$

In our problem: $e = 30\%$, $W = 200\ \text{J}$

From simple calculations:

$$Q_h \approx 667\ \text{J}$$
$$Q_c \approx 467\ \text{J}$$

Chapter 15, P8:

(a) Use the equation [15.3]:

$$e = 1 - \frac{T_c}{T_h}$$

$$T_c = (430 + 273)\ \text{K} = 703\ \text{K}$$

$$T_h = (1870 + 273)\ \text{K} = 2143\ \text{K}$$

$$e = 1 - \frac{703}{2143} = 67.2\%$$

$$W = eQ_h = 0.42Q_h$$

(b) $Q_h = 1.4 \times 10^5\ \text{J}$

$$P = \frac{W}{t} = \frac{0.42 \times 1.4 \times 10^5\ \text{J}}{1\ \text{s}} = 58.8\ \text{kW}$$

(c) The predicted efficiency for real engines is

$$e = \frac{\sqrt{T_h} - \sqrt{T_c}}{\sqrt{T_h}} = \frac{\sqrt{2143} - \sqrt{703}}{\sqrt{2143}} \approx 42.8\%$$

It is pretty close to the observed efficiency.

Chapter 15, P15:

(a) First, we calculate the efficiency: $e = 1 - \frac{T_c}{T_h} = 1 - \frac{80+273}{350+273} \approx 43.3\%$

The definition of e is $e \equiv \frac{W}{Q_h}$. Thus, $W = eQ_h = 21{,}000\ \text{J} \times 43.3\% = 9.1 \times 10^3\ \text{J}$

Therefore, $P = \frac{W}{t} = \frac{9.1 \times 10^3\ \text{J}}{1\ \text{s}} = 9.1\ \text{kW}$

(b) $Q_c = Q_h - W = 21{,}000\ \text{J} - 9100\ \text{J} = 1.19 \times 10^4\ \text{J}$

Chapter 15, P16:

(a) $e = 1 - \frac{T_c}{T_h} = 1 - \frac{5+273}{20+273} \approx 5.12\%$

(b) The definition of power is $P = \frac{W}{t}$.

Thus, the absorbed energy per hour is $W = Pt = 75 \times 10^6\ \text{J/s} \times 3600\ \text{s} = 2.7 \times 10^{11}\ \text{J}$

From $e \equiv \frac{W}{Q_h}$, we find $Q_h = \frac{W}{e} = \frac{2.7 \times 10^{11}\ \text{J}}{5.12\%} = 5.27 \times 10^{12}\ \text{J}$

(c) The answer to this part depends on your view. In my opinion, it is worthwhile, if we can really get the maximum efficiency, i.e. 5.12%.

Chapter 15, P20:

(a) For a complete Carnot cycle, $\Delta U = 0$, that is,

$$Q_c + W = Q_h$$
$$\Rightarrow W = Q_h - Q_c = Q_c\left(\frac{Q_h}{Q_c} - 1\right)$$

In the textbook, we have shown that for a Carnot cycle $\frac{Q_h}{Q_c} = \frac{T_h}{T_c}$.

Therefore, $W = Q_c\left(\frac{T_h}{T_c} - 1\right) = \frac{T_h - T_c}{T_c} Q_c$

(b) The coefficient of performance of an ideal refrigerator is defined as $COP = \frac{Q_c}{W}$

From part (a), we find $COP = \frac{Q_c}{W} = \frac{T_c}{T_h - T_c}$

Chapter 15, P23:

From problem 20, we know $COP = \frac{Q_c}{W} = \frac{T_c}{T_h - T_c}$. In our case, T_c=4 K, T_h=293 K.

Thus, $COP = \frac{4\ \text{K}}{293\ \text{K} - 4\ \text{K}} = \frac{4}{289}$. Therefore, $W = \frac{Q_c}{COP} = \frac{1\ \text{J}}{\frac{4}{289}} = 72.25\ \text{J}$.